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LONG DISTANCE EFFECTS AND CP VIOLATION in $B^{\pm} \to \rho^{\pm}\gamma$

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Abstract

We demonstrate that the long distance contribution to $B^{\pm} \to \rho^{\pm}\gamma$ may have a large effect on the decay rate and through it on the CP violating partial rate asymmetry. The change in the asymmetry can be between a factor of 0.4 and 1.4 with respect to the effect of the short distance contribution alone, depending on the values of the CKM parameters ρ and η .

1.*Introduction*

Interest in rare B decays lies mainly in their potential role as precision tests of the Standard Model (SM) . Measurement of the relevant decay rates will provide useful information about the Cabibbo-Kobayashi-Maskawa (CKM) [1] matrix elements. In particular $|V_{td}|$ is a parameter of crucial importance in the SM and it is still very poorly known. It is unrealistic to expect a measurement of $|V_{td}|$ from t-quark decays in the near future. One would then like to find alternative processes to determine $|V_{td}|$, e.g. processes that are dominated by virtual t-quarks. The present constraints on $|V_{td}|$ are derived from the experimental value of the $B_d^o - \bar{B}_d^o$ mixing parameter $x_d \equiv \Delta M/\Gamma$. The mass difference ΔM is calculated from the usual box diagrams. Even though the value of the t quark mass is known [2], this calculation is still hindered by the uncertainty in the decay constant f_B. $|V_{td}|$ can be determined precisely from the decay $K^+ \to \pi^+\nu\bar{\nu}$, which is however very rare.

As is well known, short distance (SD or penguin) contributions play a leading role in $b \to s(d)\gamma$ decays, whose amplitudes are proportional to V_{ts} and V_{td} respectively.

Since the decays $B \to K^*\gamma$ have already been observed it is useful to understand what we may learn about CKM elements through a measurement of $B \to \rho\gamma$ decays.

Recent investigation [3] of the long distance (LD) quark level spectator contributions to these decays via vector meson dominance (VMD) ($b \to s(d)V \to s(d)\gamma$) have shown that they can be neglected. LD contributions to the decay $b \to s(d)\gamma$ via $c\bar{c}$ states are only a few percent relative to the penguin contribution because of a strong q^2 dependence of the ψ decay constants ($< 0|\bar{c}\gamma^\mu c|\psi >= i\epsilon_\psi^\mu g_\psi(q^2)$) $g_\psi(m_\psi^2) >> g_\psi(0)$. The LD contributions to the decay $b \to d\gamma$ via ρ and ω are only about $3\% \cdot (V_{ub}^*/V_{td})$ relative to the penguin contributions [3].

Another source of LD contributions to $b \to d\gamma$ could come from penguins when we take into account the difference between u and c quark masses. However Soares [4] has claimed that this contribution is only about $7\% \cdot (V_{ub}^*/V_{td})$ of the penguin, so we will neglect it. On the other hand LD contributions to the $B^\pm \to \rho^\pm\gamma$ decays that are not of the spectator type may be significant [5].

In this paper we will investigate $B^\pm \to \rho^\pm\gamma$ decays, including the W exchange diagram (ED) in our analysis (see Fig.1a). We will show that the

ED amplitude is about $\pm 60\% \cdot V_{ub}^*/V_{td}$ of the penguin (SD) amplitude (see Fig.1b). The decay rate for $B^\pm \to \rho^\pm\gamma$ can vary by a factor of $0.7-2.5$ (with respect to the penguin contribution alone) depending on the CKM matrix elements V_{ub}, V_{td} and on the relative sign of the W exchange and penguin amplitudes.

We remark that ED and other non-penguin contributions to $B \to \rho\gamma$ were also studied in some detail in refs. [6, 7]. However, the approach of ref.[6] suffers from significant double counting in that it includes ED and VMD contributions additively. It is claimed wrongly that ED and VMD contributions emanate from two different quark diagrams. The formalism of ref.[7] basically coincides with ours regarding the ED but differs essentially from our treatment of penguin and related contributions. For instance the gluons that appear in their lowest order penguin diagrams are absorbed in our case in meson wave functions.

Measurement of CP violation in B meson systems would complement existing results in K decays and help elucidate the origin of this phenomenon. Observation of the direct CP violation in B decays would eliminate the superweak model for CP violation.

The main focus of our paper will be the CP rate asymmetry in the exclusive decays $B^\pm \to \rho^\pm\gamma$:

$$a_{cp} \equiv \frac{\Gamma(B^+ \to \rho^+\gamma) - \Gamma(B^- \to \rho^-\gamma)}{\Gamma(B^+ \to \rho^+\gamma) + \Gamma(B^- \to \rho^-\gamma)}. \tag{1}$$

which was investigated in ref. [8] without taking into account ED contributions.

An important finding of our investigation is that the exchange diagram does not contribute significantly to the rate difference of the decays of charge conjugate channels $B^\pm$ (the numerator of eq.(1)). As was mentioned above, the rate (i.e. the denominator of eq.(1)), can change by a factor $0.7-2.5$. So the CP asymmetry for the decays $B^\pm \to \rho^\pm\gamma$ will change by the same factor as the rates (compared to the SD contribution by itself). The resulting CP asymmetry could be as large as 30% within the allowed range of CKM matrix elements.

Because the ED contribution is negligible for the processes $B^\pm \to K^{*\pm}\gamma$ due to the relevant CKM factors, it can also importantly affect the interesting ratio

$$R \equiv \frac{\Gamma(B^+ \to \rho^+\gamma) + \Gamma(B^- \to \rho^-\gamma)}{\Gamma(B^+ \to K^{*+}\gamma) + \Gamma(B^- \to K^{*-}\gamma)} \tag{2}$$

2.*W Exchange Diagram contribution to* $B^\pm \to \rho^\pm\gamma$

It is well known that in some processes ED can be appreciably large i.e. of the same order or even larger than the SD (penguin) see Fig.1b, contribution [9, 10]. The exclusive decays $B^\pm \to \rho^\pm\gamma$, can occur via ED as shown in Fig.1a. In a simple constituent quark model for the B and ρ mesons (and neglecting terms of order M_ρ^2/M_B^2), the amplitude is given by [5, 10]

$$\begin{aligned} A_{ED}(B^- \to \rho^-\gamma) &= \frac{\sqrt{2}G_F f_B f_\rho M_\rho}{6M_B m_u} eV_{ub}V_{ud}^* \\ & \quad Tr[(\not{P}_B - M_B)\ \not{\varepsilon}_\gamma\ \not{q}_\gamma\ \not{\varepsilon}_\rho(\frac{1-\gamma_5}{2})] \end{aligned} \tag{3}$$

The QCD correction factor $[C_2(M_B)+C_1(M_B)/3] \approx 1$ has been absorbed, m_u = 330 MeV is the constituent mass of the u quark and we used the following definition for the decay constants f_B and f_ρ ($f_\rho \approx 216 MeV$)

$$< 0|\overline{u}\gamma_\mu d|\rho^- > \equiv i\varepsilon_\rho^\mu M_\rho f_\rho, \qquad < 0|\overline{u}\gamma_\mu\gamma_5 b|B_u^- > \equiv i f_B P_B^\mu. \tag{4}$$

The factor m_u in the denominator of eq.(3) indicates clearly that the ED is a long distance contribution. The effective value for m_u that should be used could easily be 30% larger or smaller than the commonly used value quoted above. This then constitutes an intrinsic uncertainty in our estimate of the ED amplitude (see however a comment at the end of the paper).

Evaluating the trace in (3) we get

$$\begin{aligned} A_{ED}(B^- \to \rho^-\gamma) &= \frac{\sqrt{2}G_F f_B f_\rho M_\rho}{3M_B m_u} eV_{ub}V_{ud}^* \\ & \quad \{i\epsilon_{\mu\nu\alpha\beta}\varepsilon_\gamma^\mu q_\gamma^\nu \varepsilon_\rho^\alpha p_\rho^\beta + (\varepsilon_\gamma p_\rho)(q_\gamma\varepsilon_\rho) - (p_\rho q_\gamma)(\varepsilon_\gamma\varepsilon_\rho)\}. \end{aligned} \tag{5}$$

We denote by p_V (p_γ) and ε_V (ε_γ) the momentum and polarization of the vector meson (photon), respectively.

3.*Short Distance contribution to* $B \to \rho\gamma$ *and* $B \to K^*\gamma$

Now we consider the SD contribution to the $B \to V\gamma$ decay ($V = \rho, K^*$). We will follow refs. [8, 11] for the calculation of the exclusive matrix elements for $B \to V\gamma$, adding $SU(3)_{flavour}$ breaking effects for the vector meson wave functions [12, 13].

The SD Hamiltonian for the decay $b \to s(d)\gamma$, is

$$H = -\frac{4G_F}{\sqrt{2}} v_q C_7 O_7, \tag{6}$$

where $q = s$ or d and $v_s = V_{tb}V_{ts}^*$, $v_d = V_{tb}V_{td}^*$. The magnetic dipole operator O_7 is (in the limit $\frac{m_s}{m_b} \to 0$)

$$O_7 = \frac{e}{16\pi^2} \bar{q}_L \sigma^{\mu\nu} m_b b_R F_{\mu\nu}, \tag{7}$$

and we will use $C_7(5\ GeV) = -.305$ [8]. The amplitude for the exclusive decay $B \to V\gamma$ is then

$$A_{SD}(B \to V\gamma) = -\frac{4G_F}{\sqrt{2}} v_q C_7 < V\gamma|O_7|B > \tag{8}$$

The transition matrix element of the magnetic operator O_7 for an on-shell photon has the general form (we neglect the vector meson mass)

$$\begin{aligned} < V\gamma|O_7|B >= eM_B F_V(O_7)\{ & i\epsilon_{\mu\nu\alpha\beta}\varepsilon_\gamma^\mu q_\gamma^\nu \varepsilon_\rho^\alpha p_\rho^\beta \\ & +(\varepsilon_\gamma p_\rho)(q_\gamma \varepsilon_\rho) - (p_\rho q_\gamma)(\varepsilon_\gamma \varepsilon_\rho)\} \end{aligned} \tag{9}$$

In the model of ref.[8] $F(O_7)$ is given by

$$F_V(O_7) = -\frac{\sqrt{M_B} C_B C_V}{4\pi^2} \int_0^1 dy \frac{y}{\sqrt{1+y}} \phi_V(y) \phi_B(\frac{M_B(1-y)}{2}). \tag{10}$$

Here $\phi_B(p) = exp(-p^2/(2p_F^2))$ is the harmonic oscillator wave function. $C_B = \sqrt{8}\pi^{3/4} p_F^{-3/2}$ and $C_V = f_V/(4\sqrt{3})$ are the normalization factors of the B meson and vector meson wave functions, respectively. $\phi_V(y)$ is the quark distribution amplitude in the vector meson ($p_{s(d)} = p_V y$ and $p_u = p_V(1-y)$). For the ρ and K^* mesons we take, respectively [13]

$$\phi(y)_\rho = 6y(1-y)\{1 - 0.85[(2y-1)^2 - \frac{1}{5}]\} \tag{11}$$

and

$$\begin{aligned} \phi(y)_{K^*} &= 6y(1-y)\{1 + 0.57(2y-1) - \\ & 1.35[(2y-1)^2 - \frac{1}{5}] + 0.46[\frac{7}{3}(2y-1)^3 - (2y-1)]\}. \end{aligned} \tag{12}$$

4.*The decay rate* for $B^\pm \to \rho^\pm\gamma$

Before presenting our results we would like to note that the relative sign of the ED and penguin amplitudes is not known. We will assume that ED has no strong phase. Such phase could arise for example from order α_s^2 QCD corrections which however are expected to be small because $\alpha_s(m_b) \approx 0.2$. Adding eqs. (5) and (8) we get

$$\begin{aligned} A(B^- \to \rho^-\gamma) = -\frac{4G_F}{\sqrt{2}} C_7 V_{tb} V_{td}^* e M_B F_\rho(O_7) \frac{A_{SD} + A_{ED}}{A_{SD}} \\ \{i\epsilon_{\mu\nu\alpha\beta}\varepsilon_\gamma^\mu q_\gamma^\nu \varepsilon_\rho^\alpha p_\rho^\beta + (\varepsilon_\gamma p_\rho)(q_\gamma \varepsilon_\rho) - (p_\rho q_\gamma)(\varepsilon_\gamma \varepsilon_\rho)\} \end{aligned} \tag{13}$$

where

$$\frac{A_{SD} + A_{ED}}{A_{SD}} = \{1 \mp \frac{f_B f_\rho M_\rho}{6M_B^2 m_u C_7 F_\rho(O_7)} \frac{V_{ub}}{V_{td}^*}\} \tag{14}$$

The rate for $B^- \to \rho^-\gamma$ is then given by

$$\Gamma(B^- \to \rho^-\gamma) = 2G_F^2 M_B^5 \alpha C_7^2 |F_\rho(O_7)|^2 |V_{td}|^2 \Omega \tag{15}$$

where

$$\Omega \equiv \left|\frac{A_{SD} + A_{ED}}{A_{SD}}\right|^2. \tag{16}$$

As is seen from eq.(5) the ED contribution is proportional to the B meson decay constant f_B. The $B_d^o - \bar{B}_d^o$ mixing parameter x_d is proportional to f_B^2 [14]:

$$x_d = \tau_B \frac{G_F^2}{6\pi^2} |V_{td}|^2 m_t^2 M_B f_B^2 B_B \eta_{QCD} F(m_t^2/M_W^2) \tag{17}$$

where η_{QCD} is a QCD correction factor and

$$F(x)=\frac{1}{4}\Big[1+\frac{3-9x}{(x-1)^2}+\frac{6x^2\ln x}{(x-1)^3}\Big] \tag{18}$$

Here $x=m_t^2/M_W^2$ and

$$m_t=\frac{m_t^{pole}}{[1+\frac{4\alpha_s(m_t)}{3\pi}+K_t(\frac{\alpha_s(m_t)}{\pi})^2]} \tag{19}$$

where $K_t \simeq 11$ [15].

Substituting f_B from eq.(17) in eq.(14) we get

$$\frac{A_{SD}+A_{ED}}{A_{SD}}=\{1\mp\frac{f_\rho M_\rho}{6M_B^2 m_u C_7 F_\rho(O_7)}\frac{V_{ub}}{|V_{td}|V_{td}^*}\sqrt{\frac{x_d 6\pi^2}{\tau_B G_F^2 m_t^2 M_B B_B \eta_{QCD} F(m_t^2/M_W^2)}}\} \tag{20}$$

Using the Wolfenstein parametrization for the CKM matrix elements [16] we obtain

$$\frac{A_{SD}+A_{ED}}{A_{SD}}=\{1+g\frac{\rho-\rho^2-\eta^2-i\eta}{[(1-\rho)^2+\eta^2]^{3/2}}\} \tag{21}$$

where g is given by

$$g=\mp\frac{f_\rho M_\rho}{6M_B^2 m_u C_7 F_\rho(O_7)}\sqrt{\frac{x_d 6\pi^2}{\tau_B G_F^2 m_t^2 M_B B_B \eta_{QCD} F(m_t^2/M_W^2)}}\frac{1}{A\lambda^3} \tag{22}$$

For our estimates we use the following input parameters [14]: $x_d=0.67\pm 0.10$, $\tau_B=(1.49\pm0.04)10^{-12}s$, $m_t^{pole}=176$ GeV [2] ($m_t=167$ GeV) , $\eta_{QCD}=0.85\pm0.05$, $B_B=1$, $\lambda=0.22$, $A=0.785\pm0.093$, $m_u=330MeV$. For the central values of these parameters we get $|g|=0.6$.

For Ω in the Wolfenstein parametrization of the CKM matrix we have

$$\begin{aligned}\Omega(\rho,\eta) &\equiv \Big|\frac{A_{SD}+A_{ED}}{A_{SD}}\Big|^2\\ &= \{1+g\frac{\rho-\rho^2-\eta^2}{[(1-\rho)^2+\eta^2]^{3/2}}\}^2+\frac{g^2\eta^2}{[(1-\rho)^2+\eta^2]^3}\end{aligned} \tag{23}$$

In Fig.2 we plot curves corresponding to constant values of Ω for $g = 0.6$ (Fig.2a) and $g = -0.6$ (Fig.2b). Note that if the ED is not taken into account ($g = 0$) , then $\Omega = 1$ for all ρ, η .

We indicate in the Figs.2-5 the region in the ρ, η plane that is allowed by present experimental bounds. The constraints on ρ and η are obtained [14] from the following experimental results

$$\left|\frac{V_{ub}}{V_{cb}}\right| = 0.08 \pm 0.03$$
$$|\epsilon_K| = (2.26 \pm 0.02) \cdot 10^{-3} \tag{24}$$

The bounds on $\left|\frac{V_{ub}}{V_{cb}}\right|$ give $\sqrt{\rho^2 + \eta^2} = \frac{1}{.22}(0.08 \pm 0.03)$ which leads to two circles centered at (0,0).

The bounds on ϵ_K lead to the hyperbolas [14]

$$\frac{1}{\eta} = 1.5 \cdot A^2 B_K + 6.6 \cdot A^4 B_K \cdot (1 - \rho) \tag{25}$$

where we will take $A = 0.785 \pm 0.093$, $B_K = 0.8 \pm 0.2$ [14].

For the branching ratio of the decay $B^- \to \rho^- \gamma$ we get

$$\begin{aligned} Br(B^- \to \rho^- \gamma) &= 2\tau_B G_F^2 M_B^5 \alpha C_7^2 |F_\rho(O_7)|^2 A^2 \lambda^6 [(1-\rho)^2 + \eta^2] \Omega(\rho, \eta) \\ &\simeq 8.2 \cdot 10^{-7} [(1-\rho)^2 + \eta^2] \Omega(\rho, \eta) \cdot \\ &\quad \Big(\frac{C_7}{-0.305}\Big)^2 \Big(\frac{F_\rho(O_7)}{-2.6 \cdot 10^{-3}}\Big)^2 \Big(\frac{A}{0.785}\Big)^2 \end{aligned} \tag{26}$$

For the ratio R in the Wolfenstein parametrization we get

$$\begin{aligned} R &\equiv \frac{\Gamma(B^- \to \rho^- \gamma) + \Gamma(B^+ \to \rho^+ \gamma)}{\Gamma(B^- \to K^{*-} \gamma) + \Gamma(B^+ \to K^{*+} \gamma)} = \left|\frac{F_\rho(O_7)}{F_{K^*}(O_7)}\right|^2 \frac{|V_{td}|^2}{|V_{ts}|^2} \cdot \Omega(\rho, \eta) \\ &= \left|\frac{F_\rho(O_7)}{F_{K^*}(O_7)}\right|^2 \lambda^2 [(1-\rho)^2 + \eta^2] \Omega(\rho, \eta) \end{aligned} \tag{27}$$

where $|\frac{F_\rho(O_7)}{F_{K^*}(O_7)}|^2 = 0.545 \pm .025$ for $p_F = 0.5 - 0.65$ GeV.

As an illustration we plot curves corresponding to constant values of R for $g = +0.6$ (Fig.3a) and $g = -0.6$ (Fig.3b) in the ρ, η plane.

5.*CP asymmetry in the decay* $B^\pm \to \rho^\pm\gamma$

We now consider direct CP violation in the decay $B^\pm \to \rho^\pm\gamma$.

In the spectator approximation the absorptive contribution to the quark decay $b \to d\gamma$ comes from the real intermediate states $b \to u\bar{u}d \to d\gamma$, $b \to c\bar{c}d \to d\gamma$, $b \to gd \to d\gamma$. The absorptive part of Hamiltonian in the spectator approximation is [17]

$$H_{ab} \simeq -i\alpha_s \frac{4G_F}{\sqrt{2}} O_7 (\frac{1}{4} C_2 \cdot V_{ub}V_{ud}^* + 0.12\frac{1}{4} C_2 \cdot V_{cb}V_{cd}^* + \frac{2}{9} C_8 \cdot V_{tb}V_{td}^*) \quad (28)$$

Here $C_2(5\ GeV) = 1.096$ [8] and $C_8(5\ GeV) = -0.185$ [18].

As explained earlier, the absorptive part of the ED amplitude is of order α_s^2. Moreover the interference of the ED amplitude with the first term in H_{ab} will not contribute to the numerator of eq. (1) either. We have also estimated the contribution stemming from the interference of the ED amplitude with the last two terms in eq.(28) and found that it enhances (reduces) for $g = -0.6$ (g=+0.6) the numerator of a_{cp} by approximately 12% with respect to the leading contribution alone. We will therefore ignore it together with the order α_s^2 contributions. We conclude that the ED can affect significantly only the denominator of a_{cp} in eq. (1). To estimate the numerator of the asymmetry in eq.(1) we follow the formalism of [8] which includes two types of contributions. The first results from the interference of the first two terms in H_{ab} with the leading penguin amplitude (see eqs.(6)-(9)) while the second includes the interference of the absorptive parts in non-spectator diagrams (see Fig. 3 in ref. [8]) with the leading penguin amplitude. Since the absorptive part comes from long distance effects, a cutoff parameter Λ for the gluon momentum, is introduced to avoid double counting with the contribution from the wave functions of the mesons [8]. The denominator of eq.(1) is calculated using eq.(15) ($\Gamma(B^- \to \rho^-\gamma) + \Gamma(B^+ \to \rho^+\gamma) \simeq 2\Gamma(B^- \to \rho^-\gamma)$).

The asymmetry a_{cp} is then given by

$$a_{cp} = -K_\Lambda \frac{\eta}{[(1-\rho)^2+\eta^2]} \frac{\alpha_s}{2} \frac{C_2}{C_7} \frac{1}{\Omega(\rho,\eta)} \quad (29)$$

where $K_\Lambda \simeq 0.97$ for $\Lambda = 1$ GeV and $K_\Lambda \simeq 1.3$ for $\Lambda = 0.2$ GeV [8].

In Fig.4 we plot curves of constant a_{cp} (a few representative values) for $g = +0.6$ (Fig.4a) and $g = -0.6$ (Fig.4b) for cut-off parameter $\Lambda = 0.2$ GeV and $\alpha_s = 0.2$.

We now estimate the total number of charged B decays required to observe this CP asymmetry at the 3σ level, $N_{3\sigma}$, assuming perfect experimental detection efficiency

$$\begin{aligned}
N_{3\sigma} &= \frac{9}{a_{cp}^2 Br(B^- \to \rho^- \gamma)} \\
&\approx 5 \cdot 10^7 \, \frac{(1-\rho)^2 + \eta^2}{\eta^2} \cdot \Omega(\rho, \eta) \cdot \\
&\quad \Big(\frac{1.3}{K_\Lambda}\Big)^2 \Big(\frac{0.2}{\alpha_s}\Big)^2 \Big(\frac{-2.6 \cdot 10^{-3}}{F_\rho(O_7)}\Big)^2 \Big(\frac{0.785}{A}\Big)^2
\end{aligned} \tag{30}$$

In Fig.5 we plot curves of constant $N_{3\sigma}$ for $g = +0.6$ (Fig.5a) and $g = -0.6$ (Fig.5b).

Summarizing our main results, Fig.4 indicates that there can be a sizable CP asymmetry in $B^\pm \to \rho^\pm \gamma$, possibly as large as 30%. Comparison of Figs. 4a and 4b shows that the long distance ED amplitude plays an important role in determining the value of the asymmetry (a factor 0.4-1.4 with respect to the pure penguin contribution), and also underlines the need to theoretically understand the relative sign of the penguin and ED amplitudes. The importance of the annihilation diagram is also apparent from Figs 3a and 3b, where the ratio R defined in eq. (2) is shown. The plot of Fig.5 shows that about $10^8 - 10^9$ charged B mesons are needed to be able to observe the CP partial rate asymmetry at the 3σ level under ideal experimental conditions. Such numbers are not out of the question for near future B factories. Finally, let us note that the magnitude of the ED contribution as presented here will be determined by checking against experiment the predictions of ref. [19] for $B \to l\nu\gamma$ where the ED is supposed to dominate the amplitude, leading to a branching ratio of about $4 \cdot 10^{-6}$ for $m_u = 330$ MeV.

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Figure Captions

Fig.1a The W Exchange Diagram (ED) for the decay $B \to \rho\gamma$

Fig.1b The electromagnetic penguin diagram for the decay $B \to V\gamma$ ($V = K^*, \rho$).

Fig.2a Curves corresponding to constant $\Omega = 0.75, 0.85, 1.0, 1.5, 2.0, 2.5$ for $g = 0.6$. The full lines show the constraints from $|V_{ub}|/|V_{cb}|$ and $|\epsilon_K|$, i.e. here and in all the following figures, the region in (ρ, η) within the full lines is allowed by experiment (see ref.[14]).

Fig.2b Curves corresponding to constant $\Omega = 0.7, 0.85, 1.0, 1.15, 1.28$ for $g = -0.6$.

Fig.3a Curves corresponding to constant $R = 0.025, 0.03, 0.035, 0.04$ for $g = 0.6$ and $|\frac{F_\rho(O_7)}{F_{K^*}(O_7)}|^2 = 0.545$.

Fig.3b Curves corresponding to constant $R = 0.01, 0.03, 0.05, 0.07$ for $g = -0.6$ and $|\frac{F_\rho(O_7)}{F_{K^*}(O_7)}|^2 = 0.545$.

Fig.4a Curves corresponding to constant $a_{cp} = 5\%, 10\%, 15\%, 20\%$ for $g = 0.6$, $\alpha_s = 0.2$ and $K_\Lambda = 1.3$.

Fig.4b Curves corresponding to constant $a_{cp} = 5\%, 10\%, 15\%, 20\%, 25\%, 30\%$ for $g = -0.6$, $\alpha_s = 0.2$ and $K_\Lambda = 1.3$.

Fig.5a Curves corresponding to constant $N_{3\sigma} = 2 \cdot 10^8, 5 \cdot 10^8, 10^9, 5 \cdot 10^9$ for $g = 0.6$, $\alpha_s = 0.2$, $K_\Lambda = 1.3$, $A = 0.785$ and $F_\rho(O_7) = -2.6 \cdot 10^{-3}$.

Fig.5b Curves corresponding to constant $N_{3\sigma} = 2 \cdot 10^8, 5 \cdot 10^8, 10^9, 5 \cdot 10^9$ for $g = -0.6$, $\alpha_s = 0.2$, $K_\Lambda = 1.3$, $A = 0.785$ and $F_\rho(O_7) = -2.6 \cdot 10^{-3}$.